Transmission for Tomorrow

A Look at
the AEP/ASEA UHV
Research Project

October 1, 1976

Foreword

"If you do not think about the future, you cannot have one."
—John Galsworthy

One may be amused today to view the seemingly crude and simple apparatus that Thomas A. Edison created to generate electricity at his Pearl Street Station and deliver it a few blocks to a handful of customers in downtown New York in 1882—the beginning of the electric power industry.

Nonetheless, the principles of operation of most of the equipment used in electric power systems today were known then, or soon thereafter. Indeed, most of the engineering advances in this industry during the 20th Century have been refinements of the previous in terms of efficiency or size or both.

Research necessary for the next advance in power transmission technology—the large step forward from extra-high voltage to ultra-high voltage—is being carried out by two partners, one from the United States and the other from Sweden, in a unique research and development project. These partners are the American Electric Power System, an electric utility, and ASEA, of Sweden, an electrical equipment manufacturer. Their project's work is now focused on the AEP/ASEA UHV Research Center, a new outdoor transmission laboratory that has risen in what was once a northern Indiana cornfield.

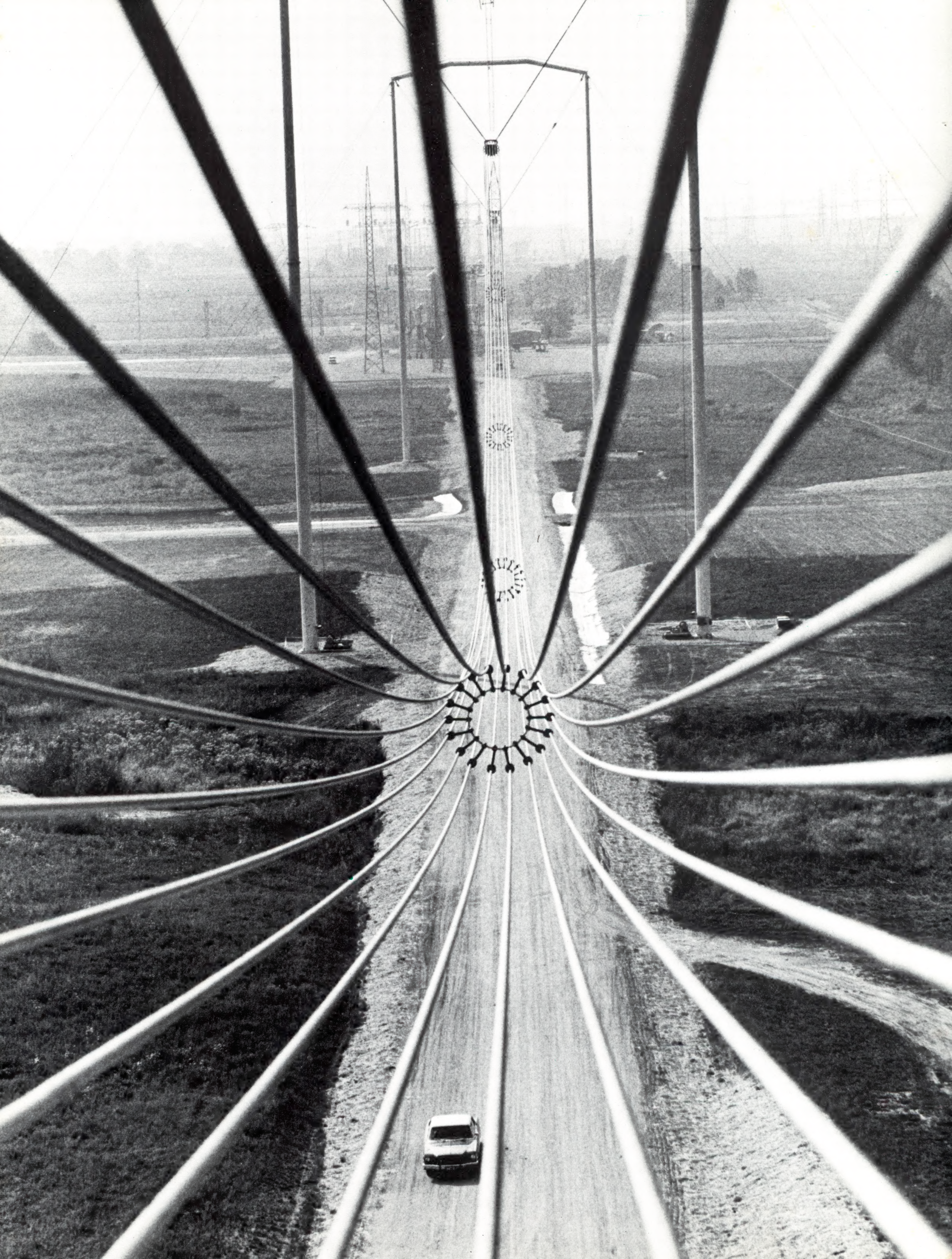
AMERICAN ELECTRIC POWER is the largest investor-owned producer of electric energy in the United States and a leader in its industry's technology. The seven operating utilities making up the AEP System provide electric service to over 6-million people in seven east-central states. These utilities are:

- Appalachian Power Company
- Indiana & Michigan Electric Company
- Kentucky Power Company
- Kingsport (Tenn.) Power Company
- Michigan Power Company
- Ohio Power Company
- Wheeling (W. Va.) Electric Company

The AEP Service Corporation is the management and technology arm of the AEP System. Its engineers, together with ASEA's engineers, are carrying out the R&D work in the subject UHV project.

ASEA is one of the world's principal manufacturers of major components for electric power systems. It, too, is a leader in high-voltage technology, both in high-voltage alternating-current transmission and especially in high-voltage direct-current transmission. Most HVDC schemes in operation or under construction in the world today are based on ASEA expertise.

Thus, these two partners have brought to the project many years of experience—one in the development and manufacture of the equipment, the other in power system operation. Together, they are seeking to find the answers that will help lead to the economical, efficient, reliable and environmentally acceptable delivery of electric energy that future generations will require. ●



Systems Analysis of UHV. The project is exploring the "why," "what," "how" and "when" of UHV transmission as it pertains to the future needs and development of an integrated electric power system, rather than looking at an isolated energy transmission link or links.

Scope. This project is not restricted to any specific UHV level. Rather, its exploration of the full UHV range, at least within the capability of the available test equipment, should lead to the eventual optimized use of any selected voltage.

Realistic Orientation. The project involves the operation of full-scale transmission station and line equipment under realistic conditions. Also, the nature of the business in which each of the two partners and the participants is engaged lends reality to their approach to the R&D work. AEP wants to provide reliable service to its customers; ASEA wants to sell reliable equipment to its customers. And all of the participants, knowing their own capabilities and specialties, can provide valuable input toward the common goal.

Historical Continuity. For AEP and ASEA, as well as for the other participants, this project is but another step in transmission progress. For example, the AEP System adopted 138 kV as its basic transmission level in 1916. As demand grew, following the depression and war years, AEP energized its 500-kV Tidd Project in 1946, leading to operation of the world's first 345-kV line seven years later. In 1961, AEP and Westinghouse Electric Corporation energized their joint Apple Grove Project, a 750-kV test center, which in turn led to operation of the world's first 765-kV line eight years later. ASEA's involvement in transmission technology has paralleled that of AEP. Sweden's 400-kV transmission system, the world's first EHV line, dating back to 1952, and the first commercial HVDC transmission, put in operation in1954, both employ ASEA equipment. Subsequently, ASEA supplied much of the apparatus used by the 300- to 500-kV systems in operation throughout the world and by the Canadian 735-kV and American 765-kV systems.

Research Center Has Four Main Areas

The UHV Research Center is located three-and-a-half miles west of Lakeville, Indiana, and 14 miles (22.3 kilometers) south of South Bend in a farmland area. It occupies a site about a mile long and a half-mile wide (1.6 kilometers by .8 kilometer), just east of Indiana & Michigan Electric Company's Dumont Station, a major switching station on the AEP System's 765-kV network.

The center comprises four principal areas:

UHV Test Station—The station is now a single-phase installation with expansion capability to three-phase operation. It comprises major pieces of equipment for circuit energization and switching, voltage transformation, surge protection, relay and control operations and measurement sensing.

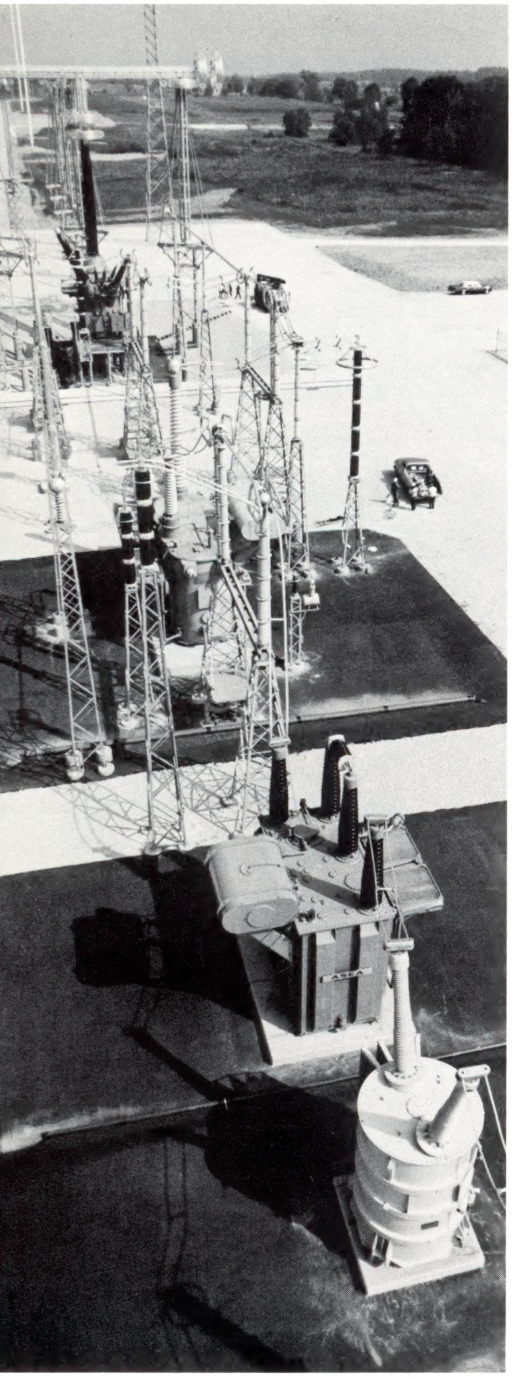
UHV Test Line—The three-span, single-phase line is 3,000 feet (915 meters) long, suspended from two deadend and two suspension towers 1,000 feet (305 meters) apart. Electrical winches on the towers can raise or lower the height of the conductor. Sensing devices along the line provide data on radio and TV interference levels, audible noise levels, corona losses and ambient conditions. Coupling capacitors at the ends of the line have suitable network connections to ground which can be used to terminate the line high-frequencies. A weather station provides such data as air temperature, barometric pressure, humidity and wind velocity and direction, for correlation with other data gathered at the site.

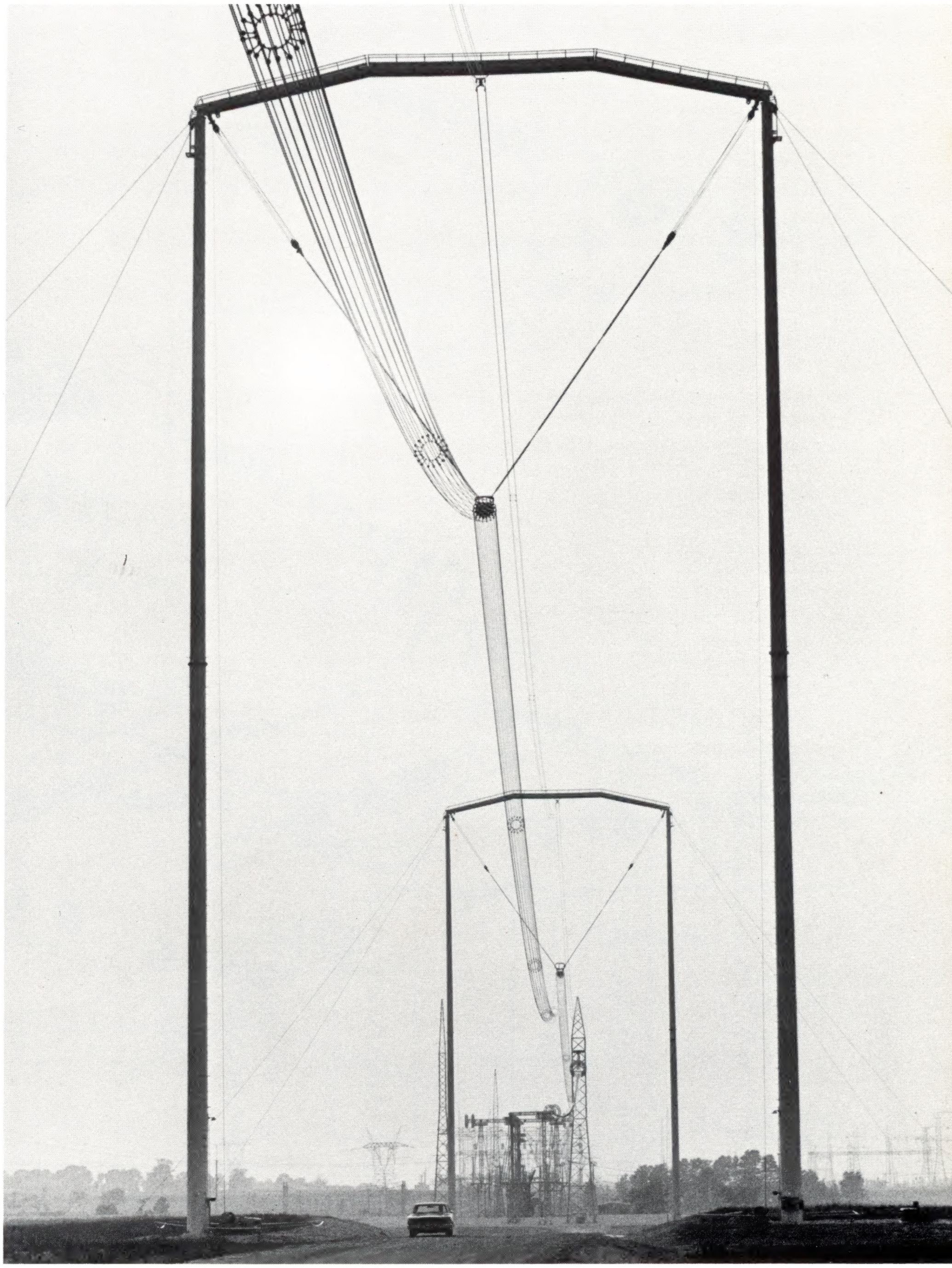
Test Cages—A test cage is a short, simulated transmission line used for the efficient, rapid evaluation of the electrical characteristics of various conductor configurations. The smaller size of the cage makes it feasible to test given configurations with a lower voltage supply, with shorter conductor lengths and at reduced ground clearance, than a full-scale line would require. Two such test cages are operated west of, and electrically independent from, the test station itself. The two cages may be operated singly or in parallel, the latter permitting simultaneous comparison of two different conductor configurations or of two samples of the same configuration. One of the features in the test cage area is a water spray system, which permits testing under simulated rainfall conditions.

Control Center—Directly opposite the test station, with a commanding view of the test line to the east and the test cages to the west, is the building housing the project's control and data-analysis center. This nerve center contains the main control console, relaying and control equipment for the station and line; the data-acquisition and analysis system for all sensors throughout the site, and the engineering offices and instrument and repair shops.

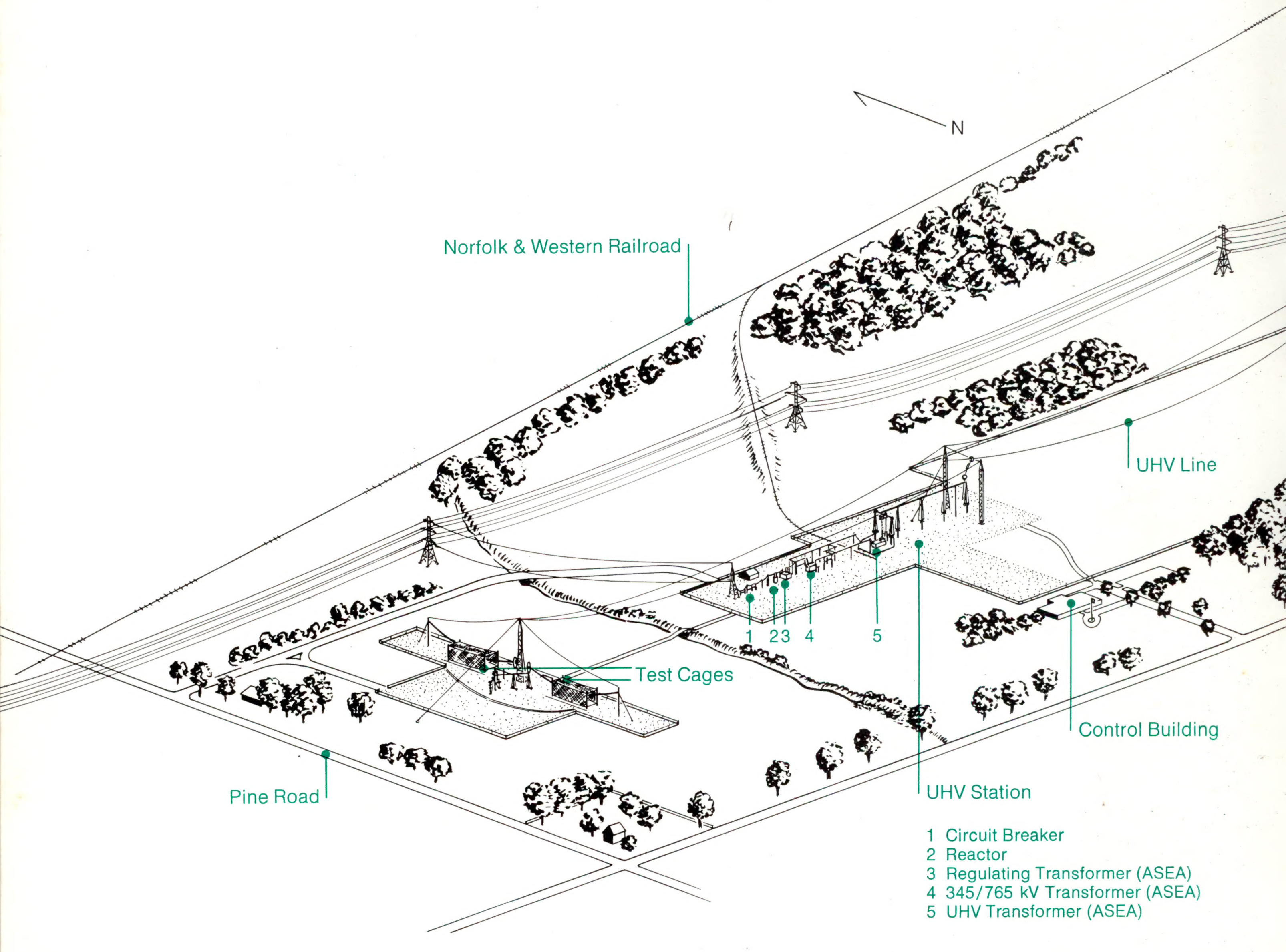
UHV test station (front to rear): reactor, regulating transformer, 345/765-kV transformer and UHV transformer.

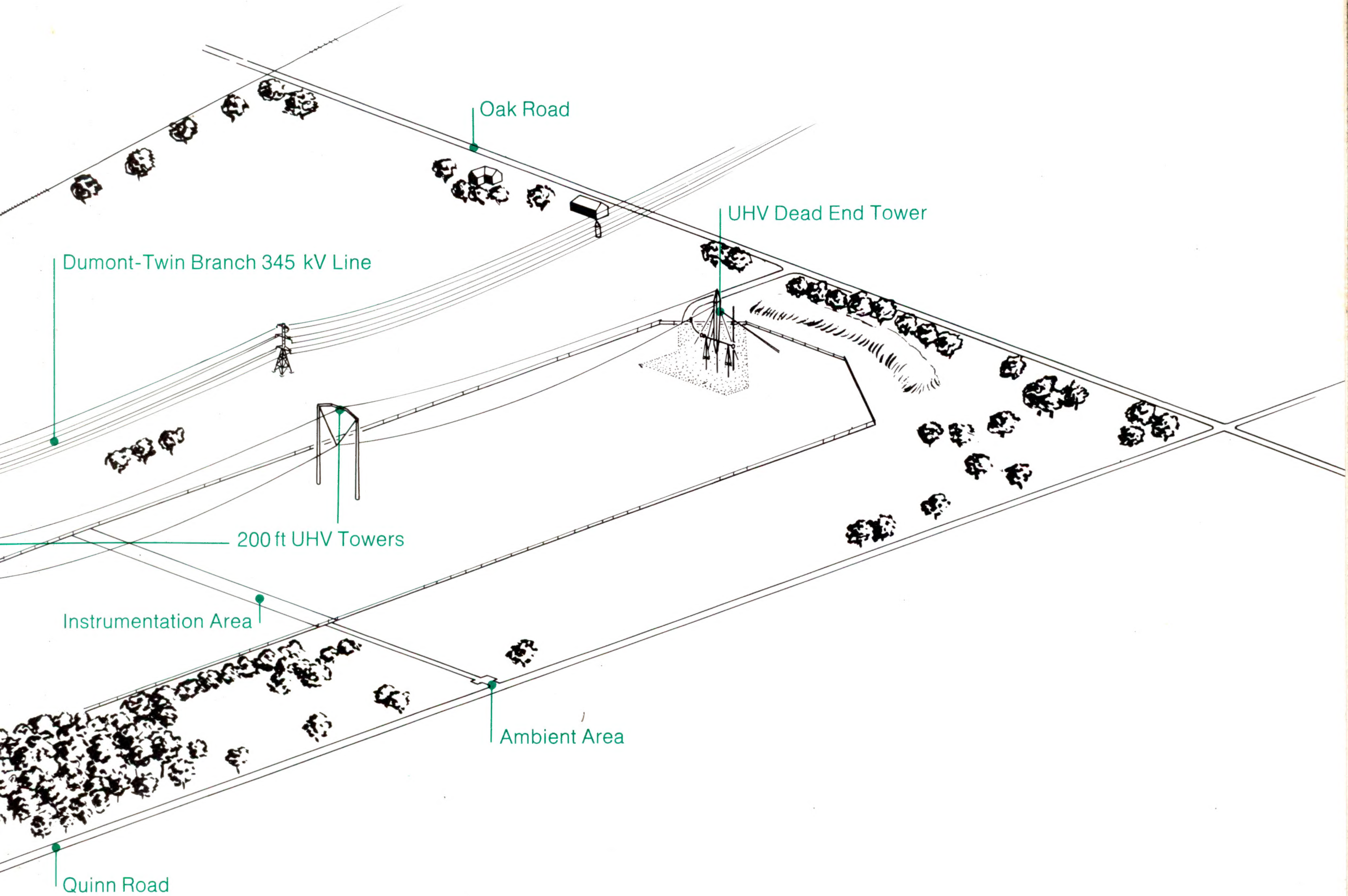
Two 214-foot arched portal suspension towers and two 165-foot deadend towers (one not shown) carry the UHV test line.



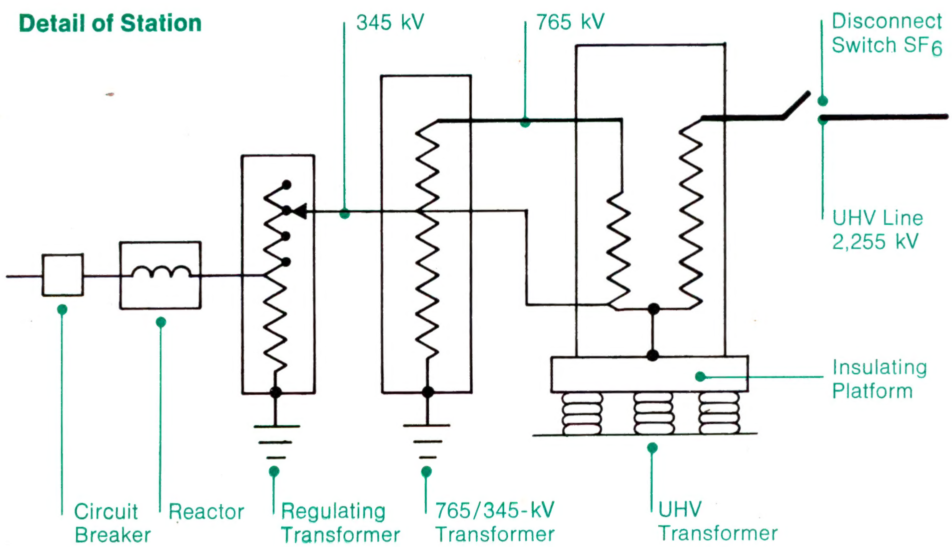


AEP/ASEA UHV Research Center





Detail of Station




ASEA

UHV transformer on insulated platform in 12-foot-deep pit. UHV lightning arrester and UHV bus support at right of transformer.

Test Station Has Three Transformers

The dominant piece of equipment in the station is the UHV transformer, one of its three transformers designed and manufactured by ASEA. The UHV transformer is rated at 420/835/1,785 kV (three-phase equivalent) and 333 MVA. It is designed with one wound limb and thus constitutes a prototype for a three-limbed 1,000-MVA power transformer. It is 57 feet (17 meters) high from its base to top of the bushing, and weighs more than 300 tons. The transformer and associated surge arresters are mounted on a steel platform resting on an insulating foundation.

The UHV transformer can be energized in either of two ways:

- A low-range connection, in which the regulating transformer—rated at 345/345 kV (plus or minus 24%) and 200 MVA—feeds the primary of the UHV transformer (with its insulated platform, and therefore the transformer case, grounded) and provides a voltage range of 1,110 to 1,817 kV (expressed in terms of three-phase equivalents).
- A high-range (cascade) connection, in which the regulating transformer energizes both the 765-kV transformer—rated 345/765 kV and 500 MVA—and the UHV transformer case (with the insulated platform now isolated from ground). Output of the 765-kV transformer is then fed into the primary of the UHV transformer. In this cascade connection, the UHV station voltage range is 1,619 to 2,255 kV (also expressed in three-phase equivalents).

All surge arresters in the station have been designed and provided by ASEA. During cascade operation the 1,090-kV surge arrester mounted between the UHV bus and the transformer platform, and the 265-kV surge arrester installed between the insulated platform and ground, must work in series to protect the UHV transformer. Series application of arresters is unusual, and this installation therefore should provide valuable operating experience for the series type of surge-arrester application.

Bus supports, potential devices, disconnecting switches and buses on the EHV side of the station are of relatively standard design. All disconnect switches for both the 345-kV regulated bus sections and the 765-kV bus sections are rated for 765-kV operation. Bus work is generally of tubular design with the exception of short connecting links of flexible bundled conductors.

UHV Station Design Is Unique

Electrically, all parts of the UHV bus and associated bus supports and bus-attached equipment must be corona-free at test-voltage levels to avoid influencing the measurements of corona on the line during evaluation of the various conductor configurations. Corona rings required at the discontinuities in the UHV bus have been made of lightweight aluminum tubing in the form of 12-foot (3.6-meter) toroids.

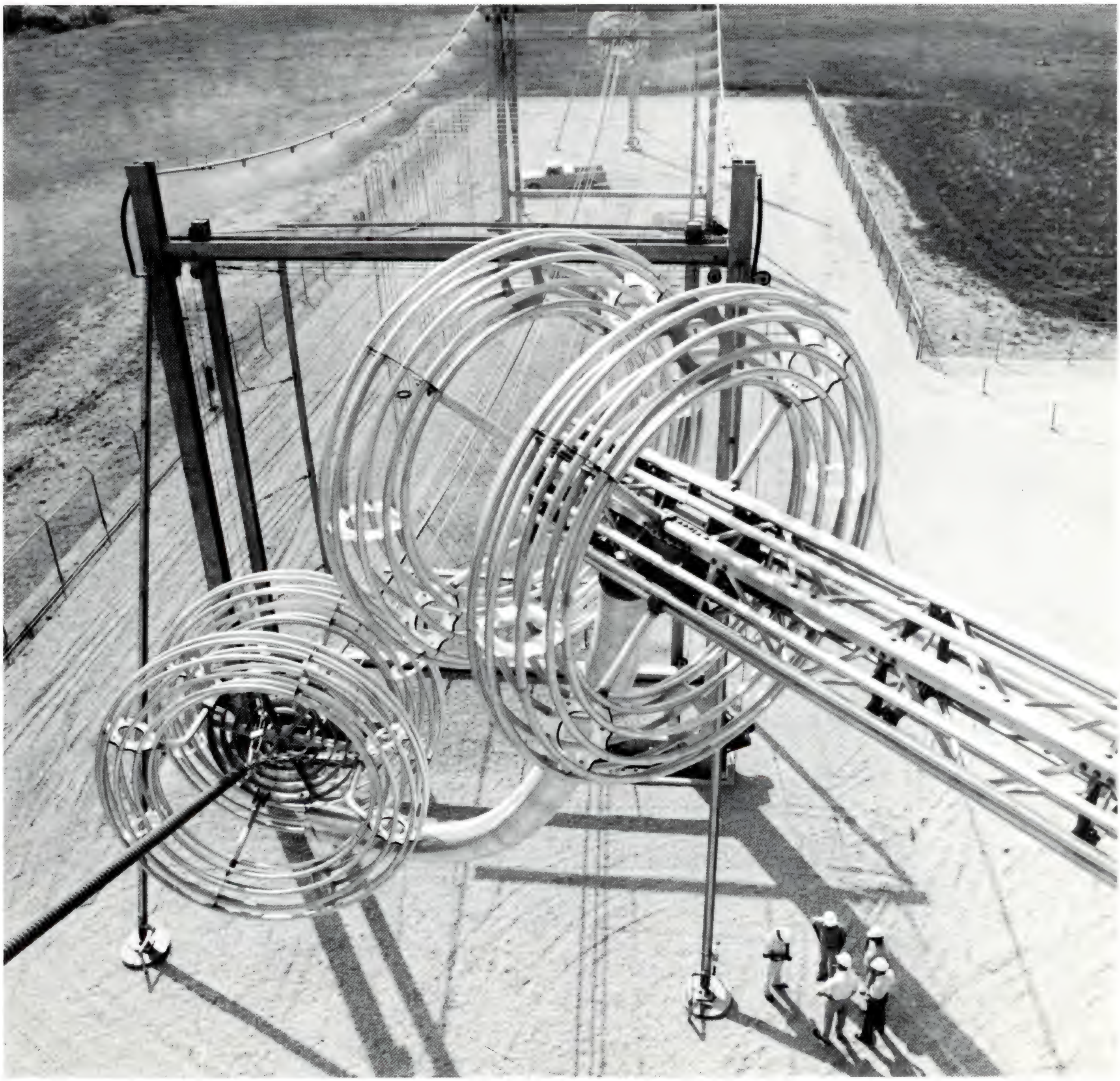
With station equipment designed for 100-mile-an-hour (161-kilometer-per-hour) winds, this has resulted in rather unorthodox designs for the insulating bus supports. These supports consist of four columns of porcelain insulators 47 feet (14.3 meters) high. Each multi-column of porcelain is guyed to the bus-insulator-support pedestal with four insulating guys of a new design by Ohio Brass. The guys, containing a series of special plastic skirts over an epoxy-fiberglass core, are extremely lightweight but strong. The same type of insulation is used in other areas of the station and for the line, where no porcelain is used. The insulating base for the UHV transformer is also made up of a large number of porcelain columns in compression and guyed by these Ohio Brass "Hi-Lite" insulators.

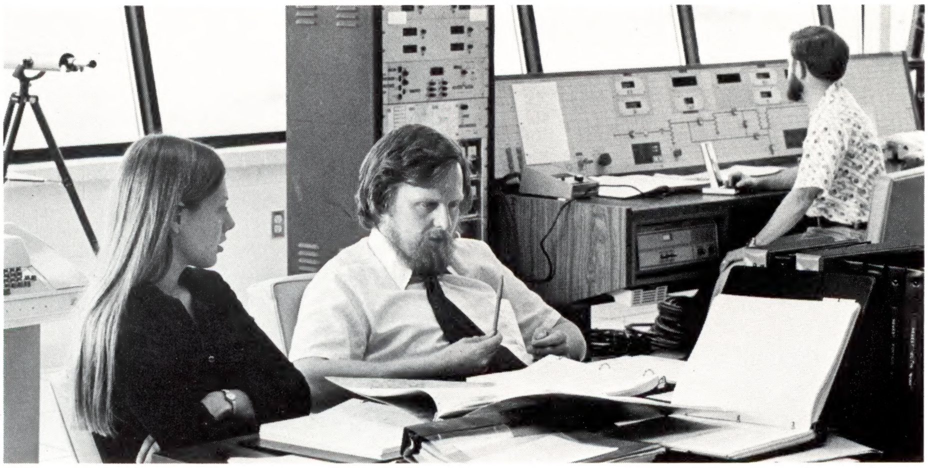
Center line of the UHV bus in the station is 75 feet (22.9 meters) above ground. A coupling capacitor installed in the station (and also at the end of the test line) has a voltage rating of 1,350 kV (line to ground). The single porcelain column is about 70 feet (21.3 meters) high.

The station area has been designed with room for change and/or expansion. When it becomes available from CGE, a UHV disconnect switch, insulated by sulfur hexafluoride (SF_6), will replace one section of the existing UHV bus. Another area near the present UHV bus is reserved for future testing of UHV circuit-breakers, shunt reactors and other equipment.

Because the UHV transformer rests on an insulated platform, power for transformer fans and pumps is supplied by a bank of three isolating transformers. Voltage and current signals from the UHV transformer, as well as relaying and control signals, are transmitted from the energized and insulated transformer base to ground potential by means of an ASEA-designed and developed Optronic system employing digital data communication via fiber-optics.

One of the two test cages in background. Photo shows connection between test bundle inside cage and the UHV bus. Note sprays of artificial rain at top of cage.





Control center showing operator's console at right. Center also houses data-acquisition and analysis systems, and relay, measurement and control equipment.

Initial Line Uses 4-Foot Bundle

The UHV station bus is connected to the conductor at the station deadend location. The conductor is protected from direct lightning strokes by a shield wire, which is itself a bundle conductor. While the shield wire location is fixed in space, height of the conductor may be varied by means of a winch at each tower leg. The conductor configuration initially is a bundle of 18 subconductors symmetrically spaced around a circle 48 inches (122 centimeters) in diameter. Each subconductor is 1.2 inches (3 centimeters) in diameter. Later conductor configurations may be symmetrical or asymmetrical and will consist of larger or smaller numbers of subconductors of varying diameter, as well as larger or smaller bundle diameters.

Height of the conductor at mid-span can be varied from 50 to 100 feet (15 to 30 meters) about ground, so that data can be obtained relative to: (1) the propagation of high-frequency currents along the test line at various heights above ground, (2) changes in lateral profiles for audible noise and radio and TV interference transverse to the test line, and (3) the effect of line height upon electrostatic fields measured at ground level.

Insulation for the conductor at the deadends consists of three 50-foot (15.2-meter) strings of Hi-Lite insulators and rated at 80,000 pounds of working load each. At the middle two towers, the conductor is suspended from V-strings of Hi-Lite insulators, also rated at 80,000 pounds. Spacers for the conductors are installed every 200 feet along the three spans. These spacers, of universal design, are easily adapted for varying numbers of subconductors and bundle diameters.

Height of the deadend towers is 165 feet (50.5 meters). The two 214-foot-high (65.6-meter) suspension towers are of an arched portal type, using two steel poles and a tubular steel cross member.

At far end of the test line, a small section of UHV bus is connected to the line by means of 18-inch (45.7-centimeter) flexible tubing. This bus is connected to ground by a 1,350-kV coupling capacitor and a suitable resistive-capacitive network to simulate the surge impedance of the line.

Basic measurements along the line are for audible noise and radio and TV interference. They are taken at a minimum of three locations in the middle span. Two locations are near the line itself, the third is remote laterally from it to obtain ambient conditions in an area outside the line's influence.

Test Cages Are Flexible

At western end of the test center are two 200-foot-long (60-meter-long) steel mesh box-like test cages. Each has a top screen, two movable side screens and a movable bottom screen, all of steel mesh. In cross-section each test cage is a square. By moving the side and bottom screens, an operator can vary the dimensions of the square from 20 to 30 feet (6.1 to 9.1 meters) on each side. In this way the voltage and gradient can be varied somewhat independently.

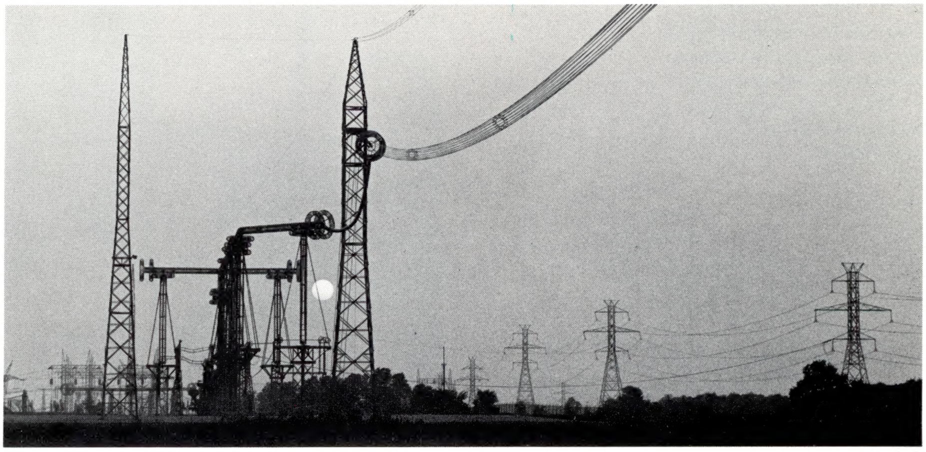
The test conductor configuration is centered in the cage. Longitudinally, the cage takes the shape of a catenary, its sag determined by the weight of the steel mesh and any required reinforcing material. By the use of tensioning devices the conductor is made to sag the same as the walls of the cages, so that the conductor is always at the same distance laterally from the cage.

Conductors in either or both cages can be energized from a common voltage source. Basic measurements to be made for each conductor configuration under test will include audible noise, radio and TV interference, and corona loss during both wet and dry conditions. Each cage has a water spray system capable of varying the volume of the spray to simulate various rates of precipitation.

Results from a large number of tests on various conductor configurations in the cages will be evaluated to determine which of them should be installed in the test line itself. The test cages, rather than the test line, will also be used to optimize possible conductor configurations, because these can be changed rapidly and inexpensively and testing there can be conducted efficiently by using semi-controlled simulated weather conditions. Configuration changes on the test line itself would involve considerable cost for reconductoring, long periods of time for testing, and the inability to control climatic conditions.

Control Center Serves Many Functions

The main building on the test site houses offices, laboratories and the project's nerve center, a control room and data-processing center 35 feet (10.6 meters) square. The station is energized from the control console by energizing the 345-kV circuit-breaker. From here the ultra-high voltage range is also varied by remote operation of the tap changer on the regulating transformer. The control my later be expanded to include remote operation of the test cages and test line as well.



Displayed on the control console are a "mimic bus," indicating the position of all disconnect switches in the station, status of the circuit-breaker used to energize the station, and all pertinent voltages, current and tap positions for various locations in the station area.

All primary and backup relaying and control signals are processed through four relay racks. This equipment monitors all pertinent voltages and currents, initiates trip and energizing signals, and annunciates various alarm conditions. For alarm or trip conditions processed through the Optronic System there is also a printout to indicate station conditions at the time.

Also installed in the control room are the data-acquisition and analysis systems. The data-acquisition system scans the inputs from each sensor once a minute, converts the data to suitable engineering units, and stores the results on magnetic disk for later transfer to magnetic tape. Data thus acquired are also available for display on a CRT or teletype console. The data-acquisition system also has the capability to signal the operator and print out errors in data, instances of equipment malfunction or power failures that may occur during unattended operation. This is important, because the station and line are expected to operate 24 hours a day, seven days a week.

The data-analysis system takes over after the data have been transferred to magnetic tape. At the operator's discretion, the taped data can be sorted, edited or processed in any number of combinations. Many data-processing functions have already been programmed into the system. These include statistical analysis routines to determine means, variance, cumulative frequencies and distribution functions for any set of input data. Routines also are included for curve fitting and for correlation between two or more variables. Interface between operator and computer for the data-analysis system is by means of a CRT console and line printer.

The control room also serves as the communications center for the entire test site. Communications are carried out between a UHF base station and portable UHF transceivers carried by station personnel around the test site and at the nearby 765-kV Dumont Station. And the control room houses the primary fire-detection and alarm system for the building, as well as an extensive security system.

The Test Program: Current and Future

Development of UHV transmission will involve at least the same areas of concern as those involved in the development of EHV. The following electrical quantities associated with various conductor configurations will be determined: corona loss, audible noise, radio interference, television interference, electrostatic-induction effects, corona-related chemical by-products, and the effects of electric fields upon people, animals and crops.

The UHV transformer used to energize the line or other equipment will be tested itself at the same time. Its voltage and current loading will be monitored and possible faults or unusual behavior will be recorded.

A number of new measurement techniques and systems have been developed specifically for use at the test center. Data obtained by these new instruments and techniques will be correlated with those obtained from other sources. Consequently, liaison will be maintained with researchers at other UHV test facilities.

Should UHV transmission become necessary by the mid-1980s, sufficient information should be available to design an efficient UHV transmission system acceptable to the public. Over the long range, it will take time to ascertain optimum conductor configurations, determine reliability of equipment and hardware, estimate costs and evaluate the social impact of future UHV construction and operation. But, for the near future, the test program is reasonably well defined. It will include:

- Testing equipment and line operation at the higher UHV range, 1,600 kV and above, to determine how high a voltage level could reasonably be established.
- Testing the lower UHV range, 1,000 to 1,300 kV, to establish its correlation with results from other UHV test facilities throughout the world, so as to verify that the AEP/ASEA results and techniques are compatible with the others.
- And exploration of the medium UHV range, 1,300 to 1,600 kV, which even now seems to be not only feasible but a reasonable next higher voltage range for those transmission systems now operating at 500 or 765 kV. ●

Meanwhile, Environmental Research Goes On, Too

Engineers and scientists from both the electric utility industry and other organizations, such as research institutions, universities and hospitals, have long been looking into the environmental aspects of EHV transmission. With advent of the AEP/ASEA UHV work, such studies—now more important than ever—are being extended to the new, higher voltages.

Such research generally falls into three areas:

Ozone—Results of research by the industry in recent years have consistently shown that transmission lines are not responsible for the emission of any significant quantities of ozone or other gases, and therefore pose no air-pollution hazard. Extensive field measurements by AEP System engineers have detected no such emissions from its operating EHV lines, and these results have been confirmed by studies made by outside scientists. Based on results of laboratory investigations and theoretical analyses, AEP engineers do not expect to find ozone emissions from future UHV lines. Nevertheless, plans for the UHV test station call for the installation of instrumentation to detect any such emissions.

Noise—Most of the research at the UHV test station is directed at the accumulation of data on the physical quantities describing audible noise, radio- and television-frequency noise, corona loss and induced electric fields. However, concurrent research will seek to assess the significance of such measurements. For example, the degree to which audible noise might become annoying is important in establishing design criteria. Studies to quantify this (psychoacoustics) are under way. Similarly, margins required between the signal strength of broadcasting stations and of potential line interference need to be determined accurately before judgment can be made as to whether or not such interference would be objectionable. AEP research on such subjective problems is being coordinated with other industry efforts.

Biological Effects—The question of the possible effects of electrostatic and electromagnetic fields on living organisms—human, animal or plant life—is also receiving considerable attention. Based on present industry research, as well as EHV operating experience, there has been no indication of any adverse biological effects. Nevertheless, the industry has launched a major program of research in this field, and the UHV research will contribute to the overall effort. ●

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